NASA CR-170456

(NASA-CR-170456) ATS-3 16 YEAR IN ORBIT
EVALUATION (Westinghouse Electric Corp.)
35 p

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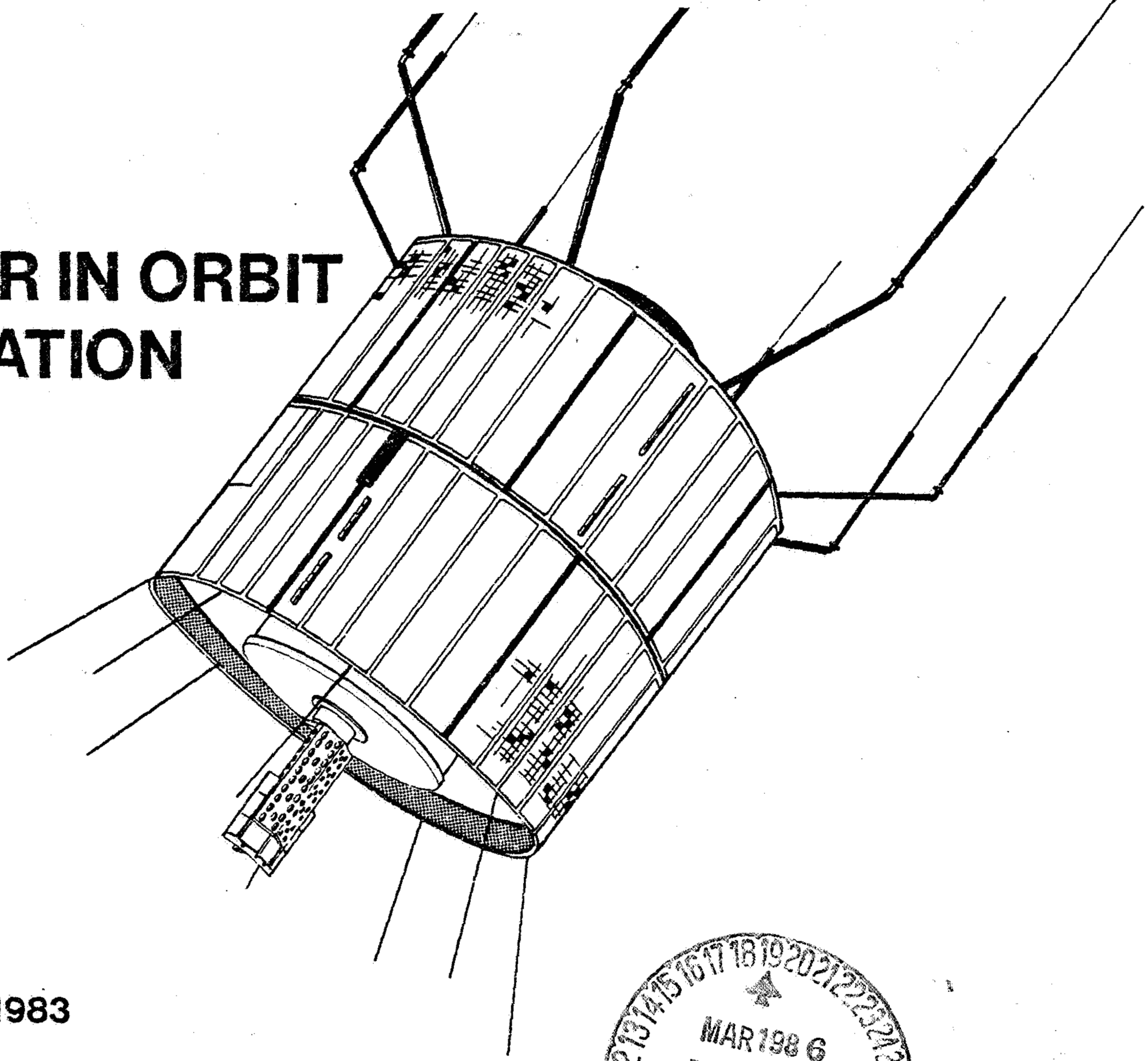

ATS-3 16 YEAR IN ORBIT EVALUATION

NAS 5-26188

NOVEMBER 1983

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Goddard Space Flight Center
Greenbelt, Maryland 20771

NASA CR 170456

APPLICATIONS TECHNOLOGY SATELLITE 3

15 YEARS IN ORBIT

EVALUATION

November 1983

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland 20771

FORWARD

The major spacecraft (S/C) subsystems on Applications Technology Satellite 3 (ATS-3) are still functional after 15 years in orbit, however, only the Very High Frequency (VHF) communications system is presently used since there is no C-band equipment at the Satellite Tracking and Data Network (STDN) ground stations.

A series of tests was performed to check the C-band and VHF Communications Systems and Power subsystem to determine the degradation of ATS-3. The C-band tests were performed at the National Aeronautics and Space Administration (NASA) Ames Research Center (ARC) due to the availability of the C-band equipment. The power subsystem tests were performed at The Goddard Space Flight Center.

The results of these tests were compared with the results obtained during the initial testing which was performed after ATS-3 was launched in November 1967, and at Rosman in November 1980.

This report is submitted to Goddard Space Flight Center (GSFC) by Westinghouse Electric Corporation in response to NASA Contract Number NAS 5-26188.

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document the operational status of ATS-3 after over 15 years of continuous operation. This is accomplished by comparing results of the End of Mission (EOM) tests with the series of similar tests performed after ATS-3 was launched in November 1967.

Throughout the years, additional testing and experiments have been performed and the results documented in the ATS Technical Data Report dated 3 March 1967 and updated through 20 July 1970 which was distributed to scientific/technical community. Other test results were documented in memos and letters with limited distribution; some of these documents are included as appendicies to this report.

1.2 BACKGROUND

The ATS-3, the third satellite in a series, was launched on November 5, 1967 using an Atlas vehicle for the first stage and an Agena booster for the second stage. A Starfinder engine, developed by Jet Propulsion Laboratories, was used to provide the extra boost required to place the spacecraft (S/C) into geosynchronous orbit.

The ATS-3 carried as its payload a package of scientific instruments and experiments. These have been classified into five groups: meteorological, communications, S/C stabilization, environmental measurements and technological.

The overall performance of the S/C has been extremely satisfactory since launch; however, as utilization of the S/C subsystems increased, certain anomalies and malfunctions occurred. The status of the subsystems as of December 1982 is described below.

- o The Power subsystem is operational. The solar array is capable of full time operation of the VHF or C-band transponders, however, the C-band is currently not being utilized due to lack of ground station C-band equipment.
- o The C-band Transponder #1 (6212/4120 MHz) is operational, with one or both Travelling Wave Tubes (TWTs). Transponder #2 (6310/4179 MHz) is operational with TWT 4 only. TWT 3 failed shortly after launch.
- o The Telemetry and Command system is operational.
- o The Mechanical Antenna Control Electronics (MACE) system is operational and is used to electronically orient the VHF beam toward the earth.
- o The Propulsion System A has exhausted its hydrazine and the S/C is now at a stable null at 105^{o} west longitude where no additional stationkeeping maneuvers are required.
- o The Propulsion System B failed when the H_2O_2 system lost pressure on launch and the remaining fuel was deliberately expended.
- o The VHF Transponder is operational and is being utilized by 12 experimenters.
- o The Resistojet is non-operational, however, it operated properly prior to deactivation.
- o The Image Dissector Camera Subsystem (IDCS) and Reflectometer have both failed.
- o The Mechanically Despun Antenna is fixed with respect to the S/C.
- o The Multi-Spectral Spin Scan Cloud Camera is not operational. The red channel has failed, however, the blue and green channels are operational. The camera cannot be used because of the failure of the Mechanically Despun Antenna.

1.3 HIGHLIGHTS

The ATS-3 has fulfilled the mission goals of the ATS Program by performing experiments in the areas of communications, meteorology, environmental measurements and S/C stabilization.

A list of participants include:

Foreign Nations: Canada, Germany, Mexico, United Kingdom, Netherlands, Norway, Venezuela, and Honduras

Government Agencies: U.S. Navy, U.S. Coast Guard, U.S. Air Force, National Oceanic and Atmospheric Administration, National Bureau of Standards, and the Department of Justice

Universities: University of Chicago, University of Hawaii, University of Miami, University of Rhode Island, University of West Indies, Florida State University, and Stanford University

Private Sector - Max Planck Institute, Woods Hole Institute, Exxon, British Broadcasting Company, General Electric

A list of highlights include:

- First color photograph of the Earth (Western Hemisphere) from the multicolor spin scan camera (November 1967).
- Performed side tone ranging experimentation with German research vessels (Gauss and Meticor) 1967.
- Experimentation with voice teletype and random sequence data with German research vessels, 1968-1969.
- Video transmission of 1968 Summer Olympics from Mexico City to Europe, 1968.
- First ground to satellite to airplane 2 way communication link took place over Atlantic Ocean, July 1968.
- Stanford University, University of Chicago and National Environmental Satellite Service performed numerous studies of cloud motion from ATS-3 photos to determine winds, cloud distributions and tornados, 1969-1978.
- Interrogation of ocean buoys (SCOMB-1) through a Norwegian ground station, Dec 1970-Jan 1971.
- Stanford Univeristy provided/transmitted computer aided instructions to Pueblo Indians in New Mexico, May 1971-June 1972.
- Performed Barium Ion Cloud Project with USA, Chile and Canada as pariticipants, 1971-1972.
- Experimentation with voice teleprinter and facsimile transmission with United Kingdom and Netherlands, 1971-1972.

- One way time dissemination experiments were conducted between fixed and mobile stations at four locations in the Western Hemisphere. Time and frequency signals were transmitted from National Bureau of Standards, August 1971-August 1973.
- Transmission of weather data, routine and daily summary reports were transmitted to ten Exxon ships in the Atlantic and Pacific Oceans, 1973-1974.
- Experimentation by U.S. Naval Fleet Analysis Center to determine the feasibility of a satellite communication network, 1977-1978.
- Provided voice and data communication between University of Miami and oceanographic ships, 1977. This is a continuing experiment.
- Provided voice and data communication between University of Rhode Island and Naval Research vessels, 1977.

2.0 C-BAND COMMUNICATION SUBSYSTEM TESTS

2.1 INTRODUCTION

The spacecraft C-Band tests were restricted to Effective Isotropic Radiated Power (EIRP) and Antenna Gain to System Noise Temperature Ratio (G/T) measurements because of the limited ground station facilities and test equipment. The first series of tests was performed at the Rosman ground station in November 1980 just prior to closing the station. The second series of tests was performed in April and May 1982 using the Ames Research Center facility.

It should be noted that all values assigned to the spacecraft are dependent upon the calibration accuracy of the ground station. Thus some discrepancy may be expected among prelaunch, in-orbit, and End of Mission (EOM) test results.

The test results are summarized in Tables 2-1 and 2-2 which include prelaunch and EOM values.

The prelaunch values shown in Tables 2-1 and 2-2 were obtained from the ATS Technical Data Report (TDR). The EOM values represent the best estimate of the true value, often derived from an average of several measurements.

2.2 SPACECRAFT EIRP

The C-band EIRP calculated values are shown in Table 2-3. Measurements were made with the spacecraft configured primarily in the Multiple Access (MA) mode with one and two TWTs. The spacecraft EIRP was calcuated from ground station measurements of receive signal strength (Prg) at the Rosman station, and from carrier-to-noise ratio (C/N) at the ARC station (refer to Appendix C for sample EIRP calculations). It should be noted that TWT number 3 failed shortly after launch; thus, no measurements were made of its EIRP.

2.3 SPACECRAFT G/T

The G/T (antenna gain to system noise temperature ratio) of a receiving system is a figure-of-merit of the system performance. A method of measuring the in-orbit G/T has been developed (Appendix A) which requires a known signal level to be transmitted to the spacecraft coupled with accurate determination of the variation of the resultant spacecraft transmitted carrier output. The technique requires that a reference be established at the ground station while the S/C is transmitting maximum power output. This was accomplished for the Rosman tests by configuring the S/C in the Frequency Translation (FT) mode and radiating enough uplink power to drive the spacecraft into saturation. An alternative method is to configure the S/C in the MA mode to establish the reference level, then reconfigure the S/C to the FT mode to complete the G/T measurement. The latter method was used for the ARC tests.

Table 2-4 shows the G/T test data. In general, each test series results in several measurement of downlink carrier suppression from the reference level. The measured carrier suppression is used to compute the G/T as described in Appendix D. The resulting values are averaged together to obtain the best estimate of G/T. The standard deviation (S.D.) of each data set is also presented.

2.4.1 Summary

- o The EIRP from the 4 watt TWTs (TWT No. 1 & 2) has not significantly degraded since launch
- o The EIRP from the 12 watt TWT (TWT No. 4) in within 3 dB of prelaunch value (TWT No. 3 failed shortly after launch)
- o The G/T of both repeaters is within 1.0 dB of prelaunch value

2.4.2 EIRP Data Analysis

The measurement of spacecraft EIRP is dependent upon accurate knowledge of the ground station receive parameters; either the station G/T or an accurate calibration of the receive signal level. The ground station G/T was used at ARC while the measurement at Rosman relied upon the station calibration of receive AGC. From Table 2-3 it may be seen that the ARC data consistantly shows a higher EIRP than observed at prelaunch (1.7 to 2.6 dB); this is extremely unlikely and probably is due to a systematic error in the measurement. Possible sources of such an error are:

- o Calibration errors in ground station parameters
- o Systematic error in identifying the ATS-3 received signal level

In either case, it is clear that the ARC measurements need to be adjusted downward. An appropriate adjustment is the average by which the calculated EIRP exceeds the prelaunch value (2.0 dB). The numbers shown in Table 2-1 reflect this adjustment.

Since the ATS-3 antenna is stationary with respect to the spacecraft body, the signal sweeps across the earth at the spin rate of the spacecraft (approximately 0.7 sec/rev) and it is thus difficult to identify the maximum signal strength. This poses significant problems in measuring the EIRP regardless of which technique is used.

From Table 2-3 it may be seen that the Rosman data is consistantly lower than the prelaunch values. This could be due to actual degradtion of the spacecraft TWT output or it could be due to systematic errors in the measurement or a combination thereof.

Overall, the data indicates that, in the worse case, the 4 watt TWTs have degraded not more than 3 dB (this consistant with measurements of the 4 watt TWTs on ATS-1), while the 12 watt TWT may have degraded by as much as 4 dB. The actual EIRP is probably somewhere between the Rosman and adjusted ARC values, which are shown averaged together in Table 2-1.

2.4.3 G/T Data Analysis

The G/T meausurement depends upon accurate knowledge of ground station EIRP and the resulting changes in ground station received signal level as the uplink EIRP is varied (the absolute receive level is not required). The ARC station was independently calibrated for EIRP shortly before the ATS-3 measurements were made, thus there was high confidence in the data.

Table 2-4 shows the measured value of transmitter power which corresponds to calculated values of spacecraft G/T for repeater 1 and 2. The values for each repeater are used to obtain the mean and standard deviation. The resulting values agree remarkably with prelaunch values (0.5 dB for repeater 1 and 0.2 dB for repeater 2) as shown in Table 2-2.

Table 2-1 ATS-3 EIRP TEST RESULTS

	Pre-Launch			Post Launch EIRP(1)		EOM EIRP		
	Tx Pwr (dB)	Ant Gain (dBm)	EIRP (dBm)	Ros 2/68 (dBm)	Moj 5/68 (dBm)	Ros 11/80 (dBm)	ARC 4/82(3) (dBm)	Average (dBm)
Repeater No. 1								
TWT 1	36.0	16.2	52.2			50.1	51.9	51.0W
TWT 2	36.0	16.2	52.2			49.2	52.2	51.7
TWT 1&2	38.4	16.2	54.6		55.1	53.1	55.2	54.2
Repeater No. 2								
TWT 1	40.3	16.2	56.5					
TWT 4(2)	40.3	16.2	56.5	56.4		51.2	56.3	53.8
TWT 3&4(2)	43.0	16.2	59.2					

1 Technical Data Report 7.1.1 & 7.1.2 (Moj. refers to ATS ground station located near Barstow, California).

2 TWT #3 failed shortly after launch.

3 Adjusted for systematic measurement error of 2 dB.

Table 2-2 ATS-3 G/T TEST RESULTS

	Pre-Launch			EOM
	G_{rs} (dB)	T_s (dB°K)	G/T (dB)	G/T (dB)
Repeater No. 1	16.2	31.3	-15.1	-15.6
Repeater No. 2	16.2	30.8	-14.6	-14.5

Table 2-3 ATS-3 EIRP EOM TEST DATA SUMMARY

Gnd Sta/Date	S/C CONFIG		GND STA MEAS.					
	MODE	TWT	C/N_O (dB)	C/N_O (dB/Hz)	Prg(1) (dBm)	Prelaunch (dBm)	Calculated (dBm)	Δ from Prelaunch (dB)
Ros 11/80	WBDM	1			-91	52.2	50.1	-2.1
	MA	1			-91	52.2	50.1	-2.1
	WBDM	1&2			-88	54.6	53.1	-1.5
	FT	1&2			-88	54.6	53.1	-1.5
	WBDM	4			-90	56.5	51.2	-5.3
	WBDM	2			-92	52.2	49.2	-3.1
ARC 5/82	MA	1	46	84.3		52.2	53.9	1.7
	MA	1&2	49	87.3		54.6	57.2	2.6
	MA	2	46	84.3		52.2	54.2	2.0
	MA	4	50	88.3		56.5	58.3	1.8

(1) Rosman Received Signal Strength (dBm)

Table 2-4 ATS-3 EOM C-BAND G/T TEST DATA

	Pwr(1) (dBm)	Downlink Carrier (dB)	Noise(2) Sharing Correction Factor, (C.F.) (dB)	Calculated G/T (dB)
ARC 4/16 82				
RPTR 1		0(ref)		
	45.5	-2	-2.2	-16.8
	44.5	-2.5	-1.1	-16.9
	43.0	-3	-0.2	-16.3
	41.5	-3.5	-0.5	-15.5
	40.0	-4	1.2	-14.7
	38.5	-5	2.3	-14.3
	37.5	-6	3.4	-14.4
				Ave. -15.6
				S.D. 1.1
RPTR 2		0(ref)		
	44.3	-1.5	-3.4	-14.3
	42.8	-2.5	-1.1	-15.1
	41.3	-3.5	0.5	-15.2
	39.8	-4	1.2	-14.4
	38.3	-5	2.3	-14.0
	37.3	-6	3.4	-14.1
				Ave. -14.5
				S.D. 0.5

(1) Pwr Corrected for -3 dB polarization loss.

(2) C.F. is a correction factor which accounts for the noise power sharing of the spacecraft transmitter output. Its value is a fuction of the carrier suppression (refer to Appendix A).

(3) Appendix B describes the calculation of G/T and presents a sample calculation.

3.0 VHF COMMUNICATIONS REPEATER TESTS

3.1 GROUND STATION EIRP VS. SPACECRAFT EIRP

The tests performed in May 1982 indicate that the VHF transmitter number 1 output is approximately 5 dB lower than in 1970 and number 2 output is approimately 1.5 dB lower than in 1970. With both regulators and the waveform generator ON the combined output is approximately 3 dB below the 1970 results while with the wave form generator OFF (omni mode) the combined output is approximately 2 dB below the 1970 level.

Figure 3-1 shows the result of the May 1982 tests along with the graph from the ATS-1 & 3 Experimenter's Guide.

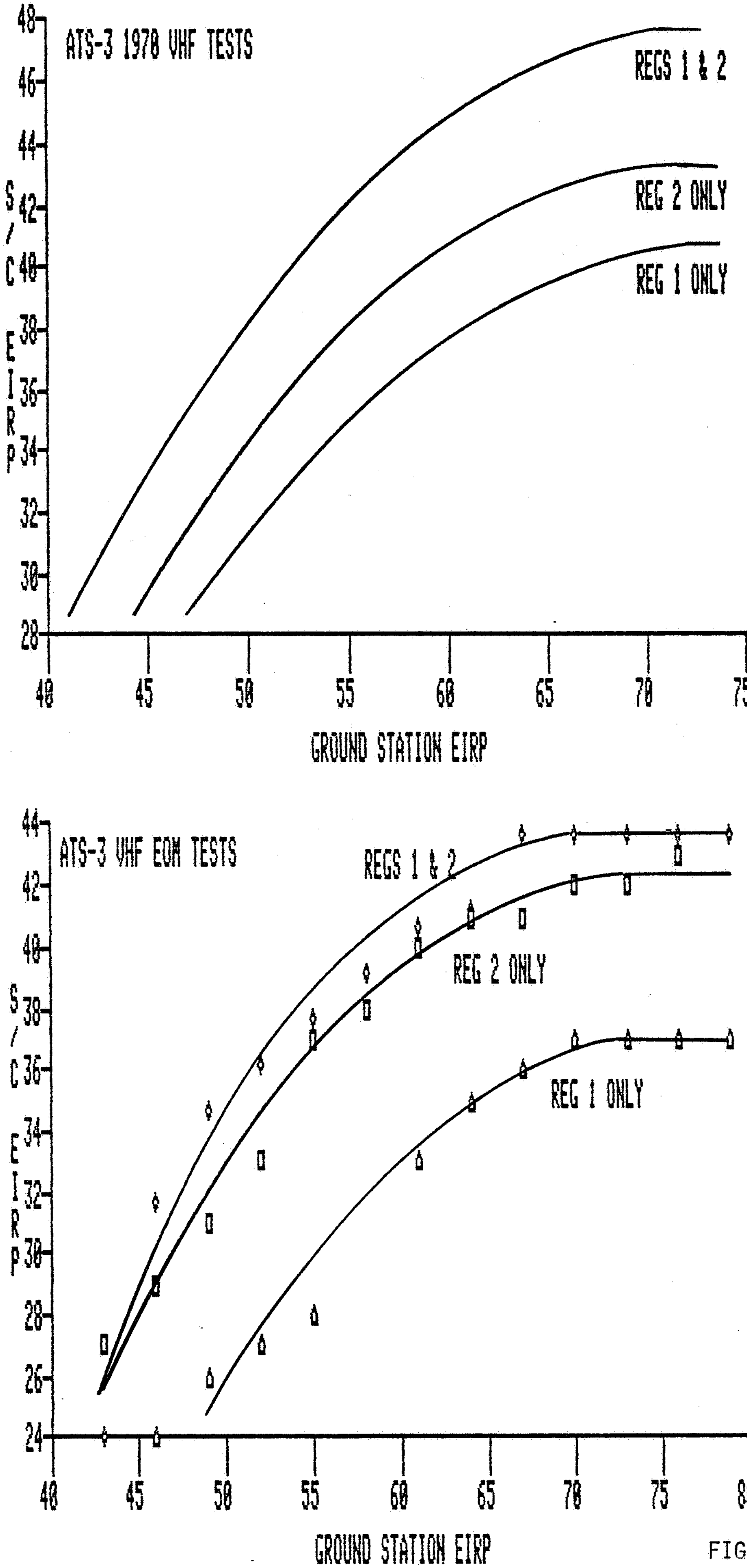
3.2 SPIN MODULATION TESTS

Figure 3-2 shows the peak to peak spin modulation amplitude vs. antenna beam position plots for the 1970 and 1982 tests.

The spin modulation has increased by about 2 dB as would be expected due to the degradation of regulator 1 transmitter output with respect to the regulator 2 output.

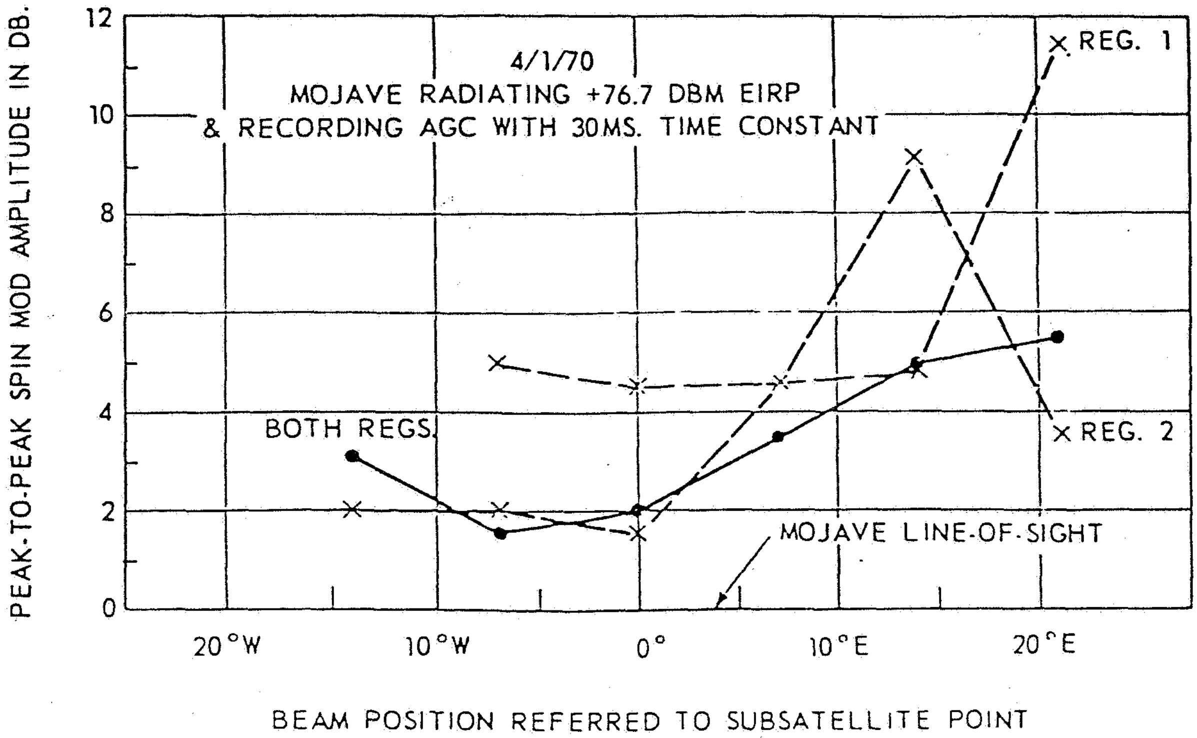
4.0 POWER SUBSYSTEM TESTS

Table 4-1 is a list of spacecraft commands and the associated command description along with the prelaunch value of the unregulated bus current change and the end of life current change. Several of the EOM current measurements are significantly different from the pre-launch figures, however these have been re-checked and confirmed. Possible explanations for the differences include degradation of the subsystem being commanded on or off, degradation of the telemetry subsystem, and degradation of the solar array panels. Figure 4-1 shows a five minute plot of unregulated bus currents



ATS-3 1970 VHF TESTS
REGS 1 & 2
REG 2 ONLY
REG 1 ONLY
S/C EIRP
GROUND STATION EIRP
ATS-3 VHF EOM TESTS
REGS 1 & 2
REG 2 ONLY
REG 1 ONLY
S/C EIRP
GROUND STATION EIRP

FIGURE 3-1


PEAK-TO-PEAK SPIN MOD AMPLITUDE IN DB.
4/1/70
MOJAVE RADIATING +76.7 DBM EIRP
& RECORDING AGC WITH 30MS. TIME CONSTANT
REG. 1
REG. 2
BOTH REGS.
MOJAVE LINE-OF-SIGHT
12
10
8
6
4
2
0
20°W
10°W
0°
10°E
20°E
BEAM POSITION REFERRED TO SUBSATELLITE POINT

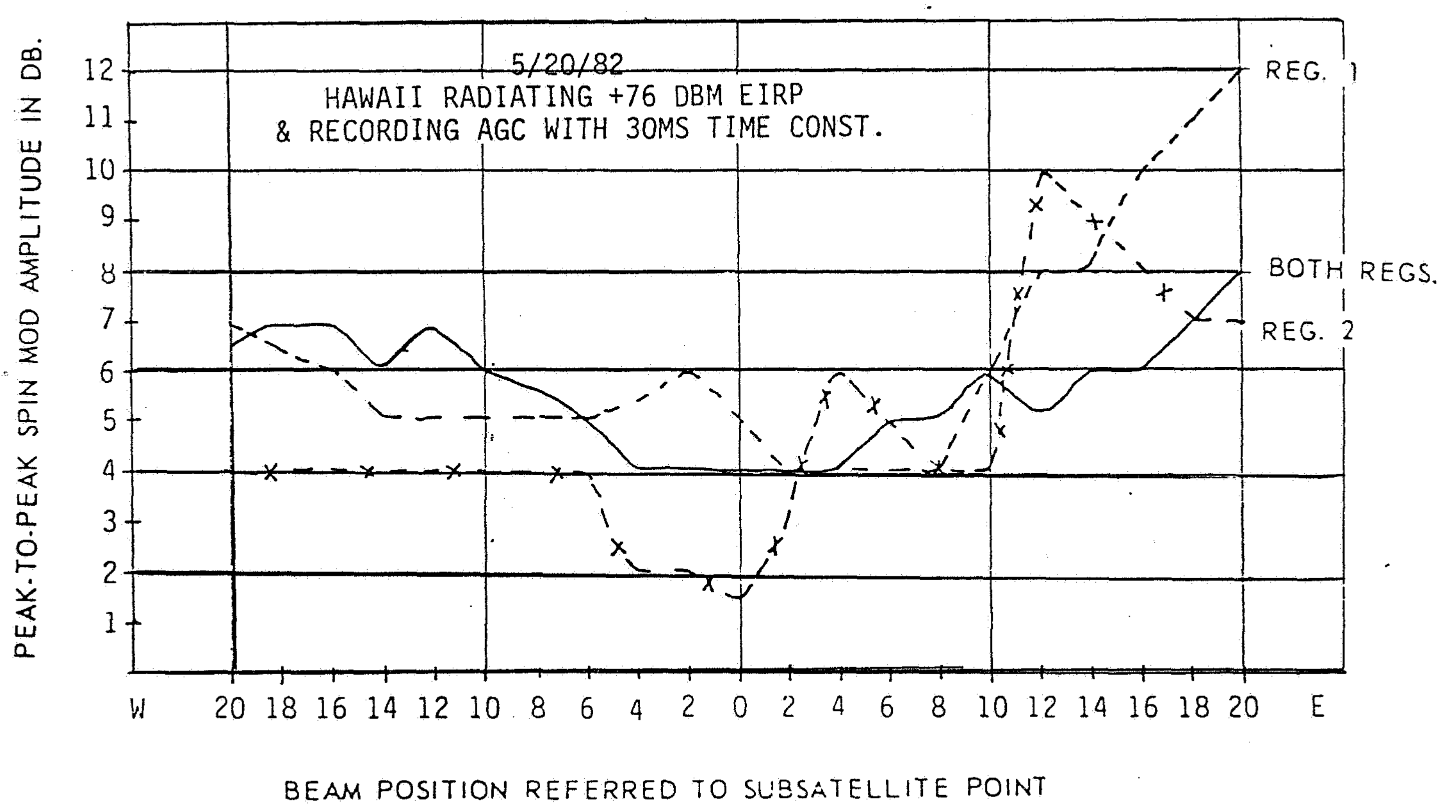

PEAK-TO-PEAK SPIN MOD AMPLITUDE IN DB.
5/20/82
HAWAII RADIATING +76 DBM EIRP
& RECORDING AGC WITH 30MS TIME CONST.
REG. 1
BOTH REGS.
REG. 2
12
11
10
9
8
7
6
5
4
3
2
1
W 20 18 16 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 16 18 20 E
BEAM POSITION REFERRED TO SUBSATELLITE POINT

FIGURE 3-2

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SQUARE 10 X 10 TO THE INCH AS 0807 GD

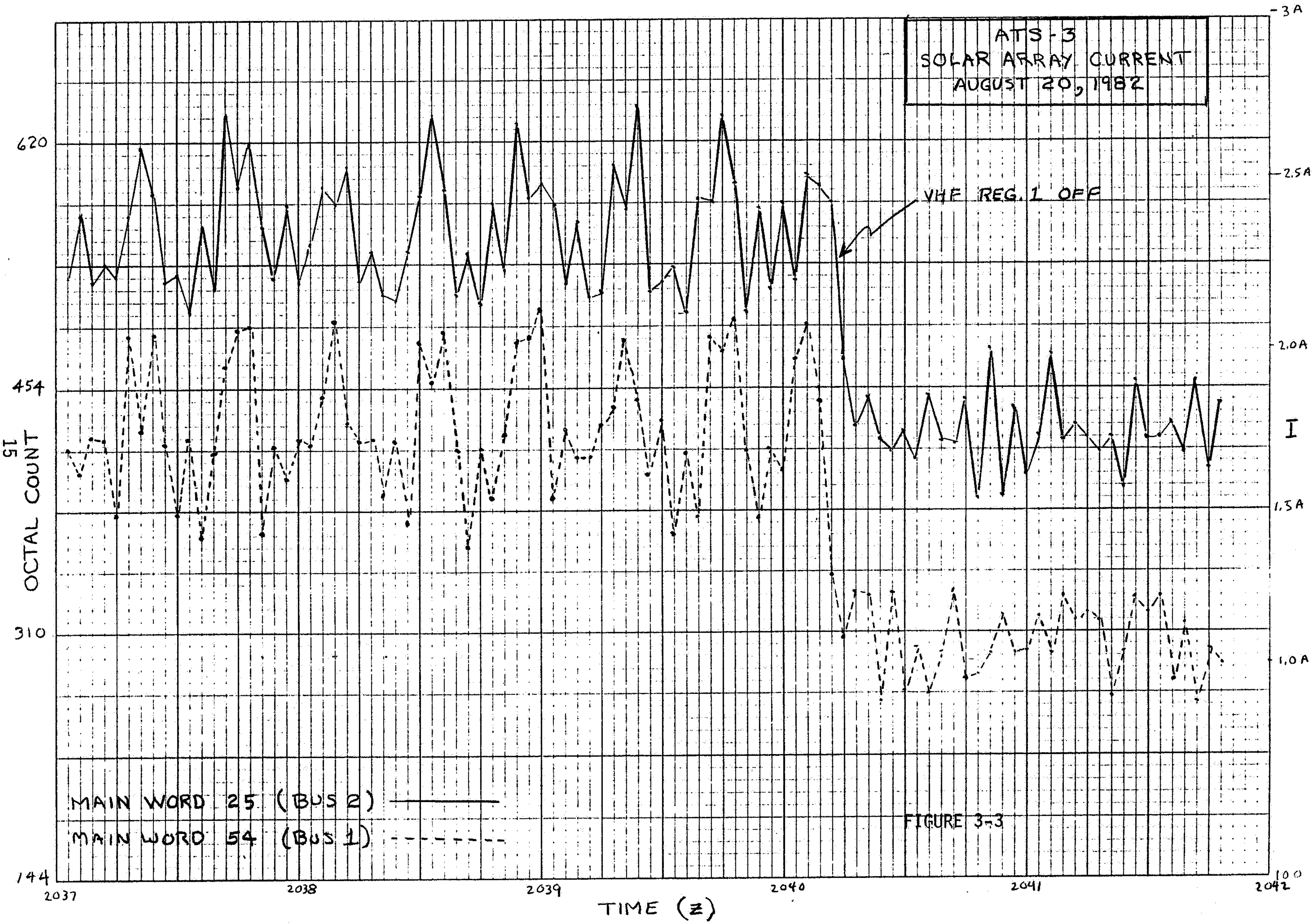

FIGURE 3-3

Table 1 Current Consumption

Command No.	Description	Prelaunch I(ma)	EOM I(ma)
147	Repeater 1 FT Mode ON	+200	+60
211	Repeater 1 MA Mode ON	+190	+50
357	Repeater 1 Wide Band Data Mode ON	+200	+60
270	Repeater 2 FT Mode ON	+210	+230
336	Repeater 2 MA Mode ON	+200	+200
060	Repeater 2 Wide Band Data Mode ON	+210	+200
022	Transponder 1 Fil. 1 ON	+125	+70
315	Transponder 1 Fil. 2 ON	+60	+50
001	TWT 1 & 2 High Voltage ON	+1280	+1330
164	Transponder 2 Fil. 3 ON	+150	+20
232	Transponder 2 Fil. 4 ON	+155	+10
126	TWT 3 & 4 High Voltage ON	+3620	+2010
201	MDA Regulator 1	+530	+660
376	VHF Regulator 1 ON	+2200	+1250
251	VHF Regulator 2 ON	+2200	+1250
006	SSCC Regulator ON	+530	+350
202	Reflectometer Regulator ON	+580	+440
261	Lamp ON/OFF	+255	+210
050	Motor ON/OFF	+105	+10
327	Reflectometer Regulator OFF		-38

under two different constant loads and indicates the difficulty in arriving at a correct value. In this report, a simple average of the readings was used. Calculations using RMS averaging were made, and were found to be within $\pm$ 0.2 amps of the simple average.

5.0 OPERATIONAL AND ANOMALY/FAILURE HISTORY

5.1 OPERATIONS

The performance of the various on-board electronics systems has been extremely successful. The operating times have been recorded daily since launch. A total compilation of operating times from launch on November 5, 1967 through July 1982 is contained in Table 5-1. As noted, some units have been operating for over 15 years, which is well beyond their expected operating life.

5.2 ANOMALY/FAILURE HISTORY

As utilization of the various S/C subsystems increased, anomalies and failures occurred. These anomalies and failures have been reported, investigated, tests performed and subsequently resolved. The history of these anomalies and failures is briefly documented in the following paragraphs.

Mechanically Despun Antenna Anomaly

After launch both Mechanically Despun Antennas (MDAs) were tested and operated normally. In the summer of 1968, the telemety indicated a fade in the C-band signal level, and that MDA 1 motor was stopping. The antenna electronics temperature telemetry indicated no thermal changes. A decision was made to switch to MDA 2, the electronic damper circuit should have stabilized the motor, however it appeared the damper circuit was inoperative.

After switching back to MDA 1, the telemetry indicated that the electronic damper circuit was operating satisfactorily. An investigation indicated that the electronic damper circuit associated with MDA 2 regulator caused the motor stoppage. A detailed description of this anomaly through July 1980 is contained in the ATS Technical Data Report, Volume 1 Section 4.1.3.

In July 1971, the MDA started to stall intermittantly, but was still used until December 16, 1975 when it finally seized for good.

Command Anomaly

The S/C was moved from its initial location at 52.3°W to 95°W in December 1967, placing it midway between the Rosman and Mojave ground stations. Shortly thereafter, spurious commands were observed. A command test was performed and it was noted that numerous spurious commands occurred in the S/C decoder. An extensive test program was performed involving ATS-1, ATS-2 and ATS-3 and utilizing the three ground stations. Commanding was done at various power levels, with the stations alternating the commanding and monitoring duties.

Results indicated that the ATS-3 decoder 2 was not defective. However, under unique conditions if the decoder was in a count mode and locked to a command receiver and a correct timing sequence existed then a valid address might occur and enable the encoder.

It was concluded that a lower address number had a greater possibility of enabling the command in an unintended S/C. This caused a change in address numbers for the ATS-4 and 5 spacecraft.

This anomaly is described in detail in the ATS Technical Data Report, Volume 1, section 4.1.3.

TABLE 5-1
ATS-3 System Operations Log
November 1967 through July 1982

SYSTEM	TOTAL TO DATE HOURS
TRANSPONDER #1	29699
TRANSPONDER #2	6002
WIDE BAND DATA MODE	27754
F. T. MODE	9714
M. A. MODE	2873
T.W.T. #1	25120
T.W.T. #2	24972
T.W.T. #3	5
T.W.T. #4	5876
TELEMETRY TRANSMITTER #1	132084
TELEMETRY TRANSMITTER #2	133144
PULSE CODED MODULATION ENCODER #1	27912
PULSE CODED MODULATION ENCODER #2	46070
SUB-CARRIER OSCILLATOR #1	99217
SUB-CARRIER OSCILLATOR #2	10467
MACE REG #1	44882
MACE REG #2	120028
VHF REG #1	68961
VHF REG #2	70217
WAVEFORM GENERATOR #1	5686
WAVEFORM GENERATOR #2	116646
MSCC REGULATOR	50341
THIRD HARMONIC GENERATOR REGULATOR	78450
IDCS REGULATOR	1790
IDCS CAMERA	1197
REFLECTOMETER REGULATOR	775
RESISTOJET REGULATOR	328
THRUSTER #1	247
THRUSTER #2	29
SELF CONTAINED NAVIGATION EXPERIMENT REGULATOR	15280
MDA REGULATOR #1	24834
MDA REGULATOR #2	4686

APPENDIX A

In-orbit Measurement of G/T of A Hard-limiting Transponder with AGC

The technique of measuring G/T is essentially one of measuring the system noise temperature. This is readily accomplished for a linear amplifier using well established techniques developed for measuring amplifier noise figure, i.e., measure the amplifier output power with no input, then measure the change in output with a known input. The problem becomes more complex if the amplifier contains a hard limiter which will limit on receiver noise. Some assumptions must then be made as follows:

1. The total output power is constant for all input levels
2. The intermodulation products due to front end noise are negligible

Using the above assumptions, the spacecraft noise power input, P_n, referred to preamp input is:

$$P_n = KTB \tag{1}$$

where:

K = Boltzman's constant = $1.38\ (10)^{-23}$ w/°/Hz (-198.6 dBm/°/Hz)

T = Spacecraft system noise temperature (°Kelvin)

B = Spacecraft Noise Power Bandwidth

The spacecraft output power, P_{out}, is proportional to the signal power input, P_s, multiplied by the antenna gain, G, plus the noise power input, P_n;

$$P_{out} = P_{s\ out} + P_{n\ out} = C(P_s G + P_n) \tag{2}$$

where:

C = constant of proportionality

P_s = Ground station EIRP (dBm) - path loss (dB)

For large P_sG (on the order of -70 dBm) , P_n becomes negligible, and the total output power may be considered to be due to the signal input, P_sG. The signal power output, $P_{s\ out}$, may be observed and measured on a spectrum analyzer or a narrowband tuned voltmeter. As P_s is decreased, a decrease in $P_{s\ out}$ will occur, and $P_{n\ out}$ must then increase in order to maintain constant P_{out}.

From equation (2):

at high input power: $P'_{out} = P'_{s\ out} = C'P'_sG$ (2A)

and at low input power: $P_{out} = P_{s\ out} + P_{n\ out} = C(P_sG + P_n)$ (2B)

where C is a constant of proportionality and (') is used to indicate the high power condition.

From the above, since $P_{out} = P'_{out}$, we have:

$$P'_{s\ out} = P_{s\ out} + P_{n\ out} \qquad (2C)$$

$$C'P'_sG = C(P_sG + P_n)$$

from which:

$$P'_sG = \frac{C}{C'}(P_sG + P_n) \qquad (2D)$$

From equation (2C):

$$P_{n\ out} = P'_{s\ out} - P_{s\ out} \qquad (2E)$$

Also, from (2B) and (2A):

$$P_{n\ out} = CP_n \text{ and } P'_{s\ out} = C'\ P'_sG$$

which substituted into (2D) gives:

$$P'_sG \approx \frac{P_{n\ out}}{P_n} \frac{P'_sG}{P'_{s\ out}} (P_sG + P_n)$$

Substituting for $P_{n\ out}$ from (2E) gives:

$$P'_sG \approx \frac{(P'_{s\ out} - P_{s\ out})\ P'_sG}{P_n\ P'_{s\ out}} (P_sG + P_n)$$

dividing through by P'_sG gives:

$$1 = \frac{(P'_{s\ out} - P_{s\ out})}{P'_{s\ out}} \quad \frac{(P_sG + P_n)}{P_n}$$

or

$$1 = (1 - P_{sr}) \quad \frac{(P_sG + P_n)}{P_n} \qquad (2F)$$

where $P_{sr} = \dfrac{P_{s\ out}}{P'_{s\ out}}$

Expanding (2F) yields:

$$P_n = P_n - P_{sr} P_sG + P_sG - P_{sr} P_n$$

From which

$$P_{sr} P_n = (1 - P_{sr}) \quad (P_sG)$$

or

$$P_n = \frac{1 - P_{sr}}{P_{sr}} \quad P_sG \qquad (3)$$

For the special case where $P_{sr} = 0.5$ (3 dB drop), $P_{n\ out}$ is equal to P_s out, and P_n is equal to P_sG as follows. Equation (3) evaluated for $P_{rs} = 0.5$ becomes:

$$P_n = \frac{1 - 0.5}{0.5} P_sG = P_sG$$

or

$$P_n \Big|_{P_{sr} = 0.5\ \text{dB}} = P_sG \qquad (4)$$

Substituting for P_n in equation (1) gives:

$$P_sG = KTB \text{ or } \frac{G}{T} = \frac{KB}{P_s}$$

Assuming 30 MHz spacecraft Noise Power Bandwidth:

$$G/T\ (\text{dB}) = -198.6 + 74.8 - P_s = -123.8 - P_s \qquad (5)$$

where:

P_s = Ground station EIRP (dBm) - path loss (dB)

The more general case of equation (5) becomes:

$$G/T\ (dB) = -122.6\ dB - 10 \log \frac{(1 - P_{sr})}{P_{sr}} - P_s\ (dB) \qquad (6)$$

Calculation of equation (6) is simplified by use of the nomogram shown in Figure A-1 (attached) which solves for the correction factor, C.F.;

$$C.F. = 10 \log \frac{(1 - P_{sr})}{P_{sr}} \qquad (7)$$

A basic assumption in the derivation just presented is that the signal-to-noise ratio was unchanged through the S/C limiter (essentially performing as a linear device with regard to S/N). Figure A-2 shows that the S/N transfer characteristic of a hard limiter is not linear[(1)]. This effect has been used to modify the Correction Factor curve shown in Fiure A-1. The revised curve is presented in Figure A-3.

EXAMPLE

For synchronous altitude (ATS-3 subsatellite point at 105 west longitude), Rosman C-band transmitter:

$$P_s = P_{gnd}\ (dBm) + G_{gnd}\ (dB) - L\ (dB) \qquad (8)$$

where:

P_{gnd} = Rosman T_x power (dBm)

G_{gnd} = Rosman antenna gain = 58.5 dB

L = Path loss at 6301 MHz = 203.2 dB (includes 1.5 dB pointing loss)

Thus:

$$P_s = P_{gnd}\ (dBm) - 144.7\ dB$$

Substituting (7) and (8) into (6) gives the expression for the ATS-3 spacecraft G/T as a function of Rosman transmitter power:

$$G/T\ (dB) = -123.8 - C.F. - P_{gnd}\ (dBm) + 144.7$$

$$G/T\ (dB) = 20.9 - C.F. - P_{gnd}\ (dBm) \qquad (9)$$

Similarly, for the ARC we have:

$$G/T\ (dB) = 26.6 - C.F. - P_{gnd}\ (dBm)$$

(1) Davenport, Jr. Applied Physics, June 1953.

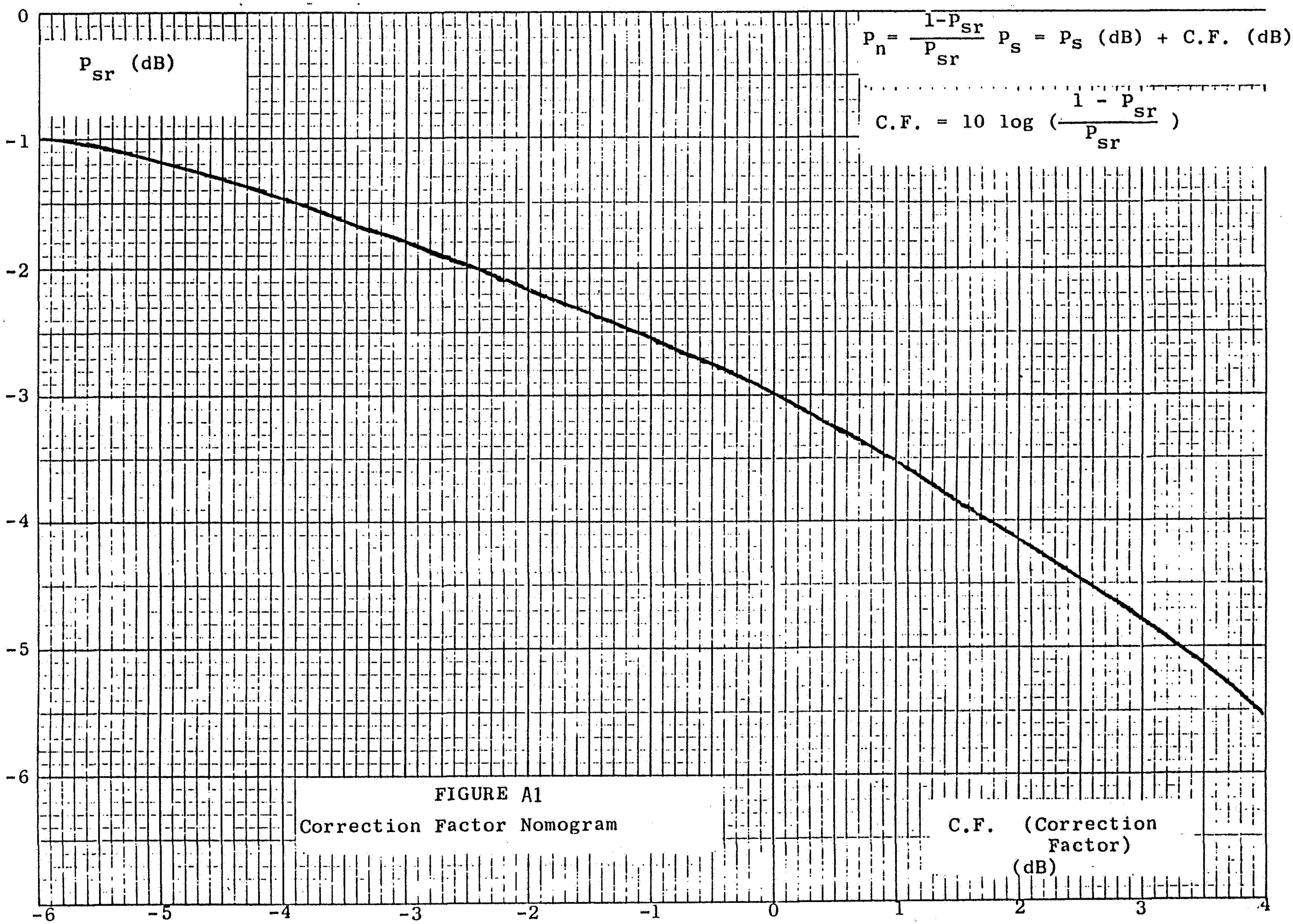

FIGURE A1
Correction Factor Nomogram

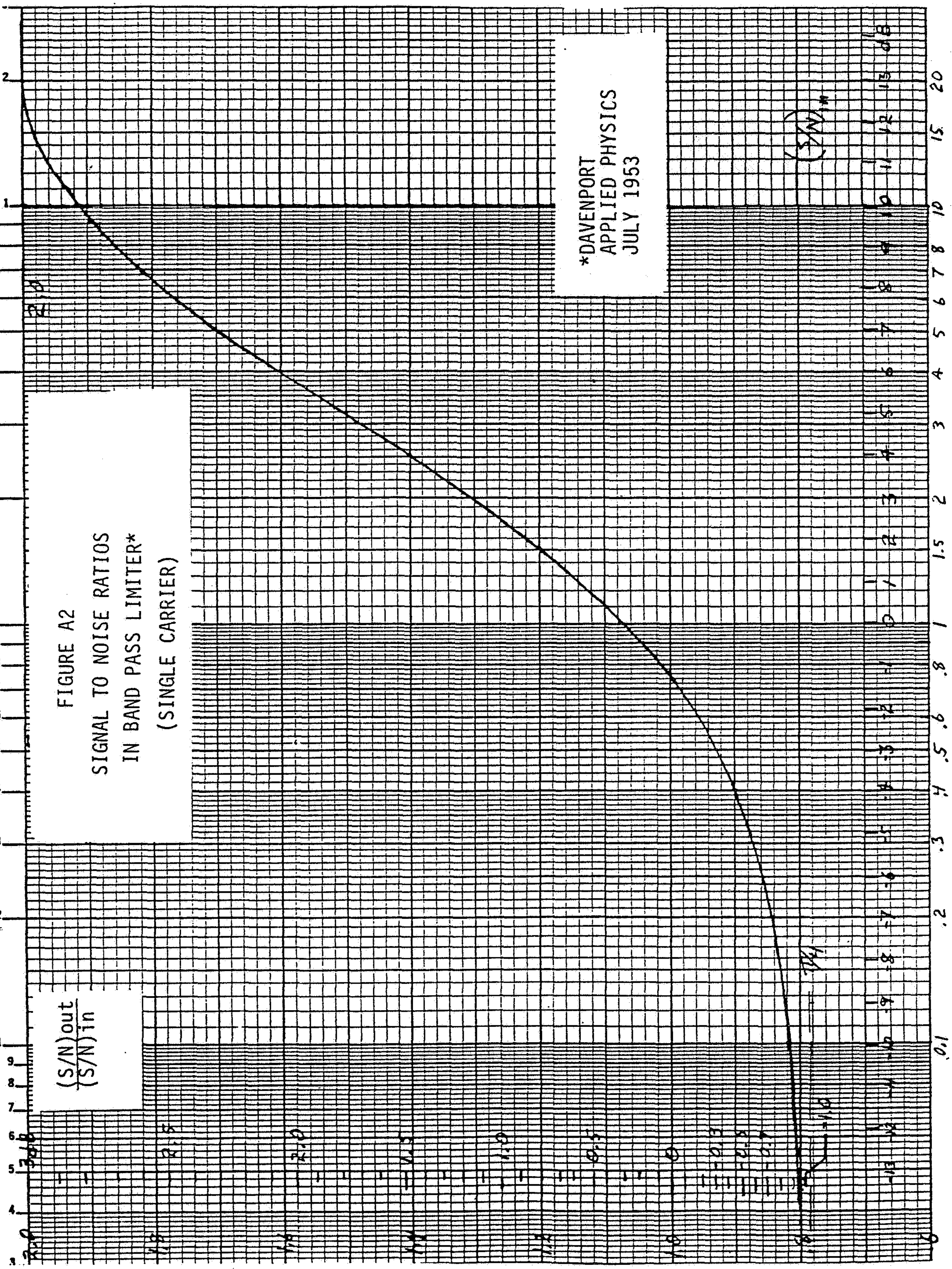
FIGURE A2
SIGNAL TO NOISE RATIOS
IN BAND PASS LIMITER*
(SINGLE CARRIER)
*DAVENPORT
APPLIED PHYSICS
JULY 1953
$\frac{(S/N)out}{(S/N)in}$
$(S/N)_{in}$

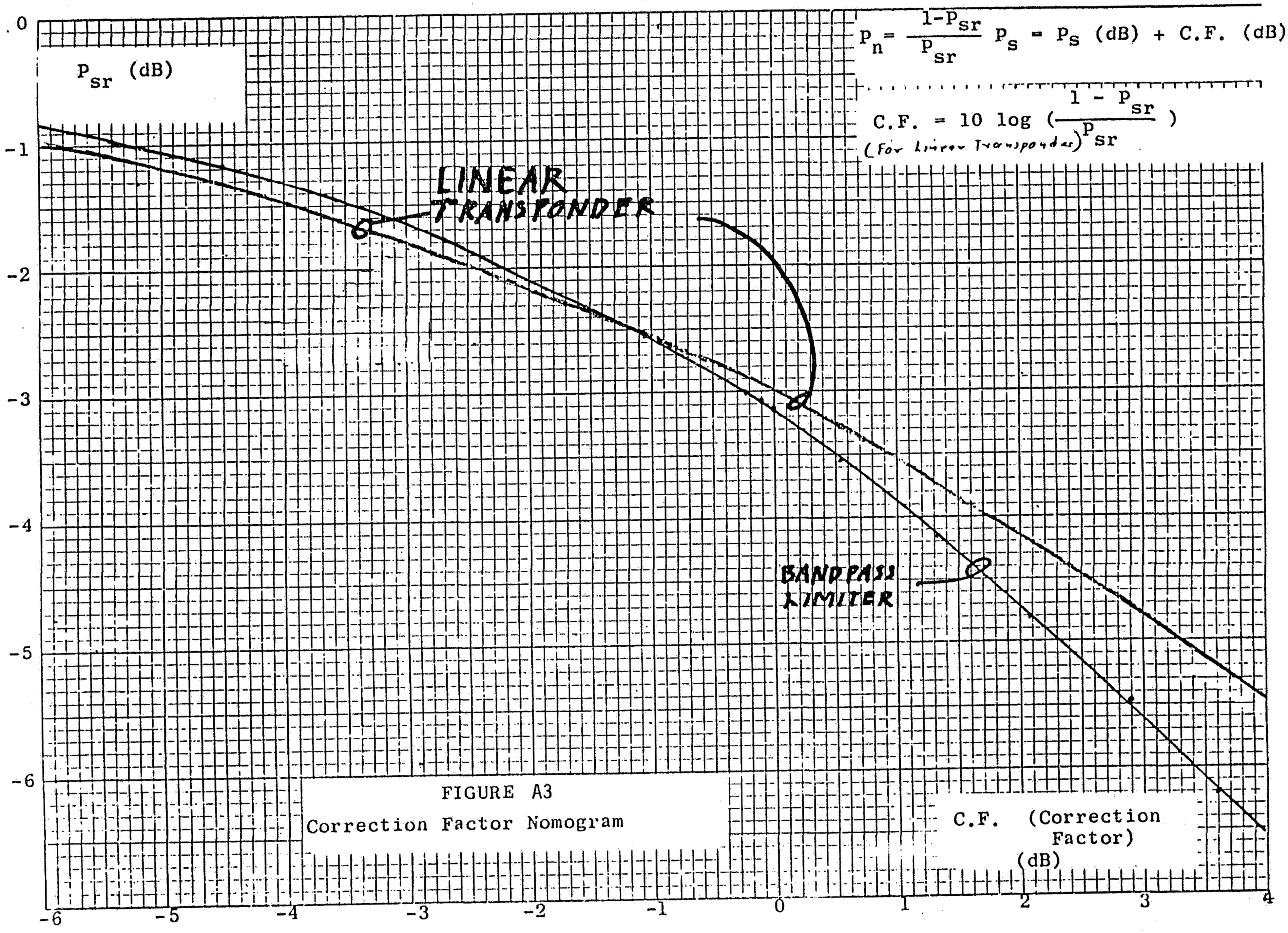

FIGURE A3
Correction Factor Nomogram

APPENDIX B

Calculation of System Noise Temperature from Specification and Prelaunch Measured Values

The spacecraft system noise temperature is dependent upon several factors; primarily the earth noise temperature, noise figure of the transponder and the receive losses of the transponder. The following formula is used to calculate the spacecraft system noise temperature referred to the preamp input.

General Formula

$$T_s = T_A + T_T + T(L-1) + L(T_R) \qquad (1)$$

where: T_A = antenna noise temp

T_T = transmitter noise spill over into RCVR band

t = physical temperature of coupling network

L = coupling network loss between antenna and receiver

T_R = LNA noise temperature

The spacecraft repeater prelaunch[1] T_R was measured to be 890°K for repeater no. 1 and 764°K for repeater no. 2. The receive antenna losses are 0.5 (1.12:1) ratio. In orbit measurements show the temperature of the coupling network to be about 285°K while 30°K is a reasonable assumption for the degradation due to transmitter thermal noise out of band. The antenna sky noise is taken to be 290°K when looking directly at the earth using the earth coverage MDA receive antenna.

[1] Tec Data Report section 7.1.1, ref.

Using these values in (1) yields the spacecraft system noise temperatures referred to the electronics input. The G/T for the prelaunch parameters is determined by dividing the measured gain by the calculated system noise temperature.

From (1) for repeater no. 1

$$T_s = 290 + 30 + 285\ (1.12 - 1) + (1.12)(890)$$
$$= 1251^{o}K = 31.3\ dB^{o}K$$
$$G/T = 16.2 - 31.3 = -15.1\ dB$$

Similarily, for repeater no. 2

$$T_s = 1209°K = 20.8\ dB°K$$
$$G/T = 16.2 - 30.8 = -14.6^{o}\ dB\ K^{-1}$$

APPENDIX C

ATS-3 EIRP Calculation

(Rosman and ARC Measurements)

$$\text{EIRP} = C/N_o - G/T + G + \text{F.S.} + \text{S/C Ant. Pntg. Loss} \qquad (1)$$

$$= \text{Prg} - G + \text{F.S.} + \text{S/C Ant. Ptng. Loss} \qquad (2)$$

where; C/N_o = the measured carrier to noise ratio density of the downlink signal measured at the ground station (corrected for ground station polarization mismatch, if any). (dB)

G/T = The measured (or calculated) ground station antenna gain to system noise temperature ratio (expressed in dB).

K = Boltzman's constant = -198.6 dBm $^oK^{-1}Hz^{-1}$

F.S. = Free Space Path Loss (dB)

Prg. = Ground station received signal level (dBm)

G = Ground station receive net antenna gain (dB)

<u>ARC - 25 May 82</u>

From (1) for repeater no. 1;

$$\text{EIRP} = C/N_o - 30.0 - 198.6 + 197.5 + 1$$
$$= (C/N_o - 30.1) \text{ dBm}$$

for system no. 2;

$$\text{EIRP} = C/N_o - 30.0 - 198.6 + 197.6 + 1$$
$$= (C/N_o - 30.0) \text{ dBm}$$

<u>ROS - 11/80</u>

From (2) for repeater no. 1;

$$\text{EIRP} = \text{Prg} - 57.4 + 197.6 + 1$$
$$= (\text{Prg} + 141.1) \text{ dBm}$$

for repeater no. 2;

$$\text{EIRP} = \text{Prg} - 57.4 + 197.6 + 1$$
$$= (\text{Prg} + 141.2) \text{ dBm}$$

APPENDIX D

ATS-3 G/T Calculation

(Rosman and ARC Measurements)

$$G/T = K + S/C\ NPBW + F.S. - G\ ant - Pg + Lp - C.F. \qquad (1)$$

where; S/C NPBW= Boltzman's Constant = 198.6 $dBm^{o}K^{-1}Hz^{-1}$

F.S. = Free space loss (dB)

G_{ant} = Ground station net transmitted antenna gain (dB)

Pg = Ground station transmitter output (dBm)

Lp = Combined spacecraft and ground station pointing losses (dB)

C.F. = Correction factor to account for noise power sharing of S/C downlink (see Appendix A)(dB)

Ames Research Center

from (1) for repeater no. 1;

$$G/T = -198.6 + 74.6 + 201.7 - 58.5 - Pg + 1.5 - C.F.$$

$$= (-Pg - C.F. + 26.6)\ dB$$

similarly, for repeater no. 2;

$$G/T = (-Pg - C.F. + 26.7)\ dB$$

APPENDIX E

Acronyms and Abbreviations

ARC	Ames Research Center
ATS	Applications Technology Satellite
C/N_o	Carrier Power to Noise Power Density Ratio
EIRP	Effective Isotropic Radiated Power (referred to an isotropic antenna)
EOM	End of Mission
FT	Frequency Translation
GSFC	Goddard Space Flight Center
G/T	Antenna Gain to System Noise Temperature Ratio
MA	Multiple Access
MACE	Mechanical Antenna Control Electronics
MDA	Mechanically Despun Antenna
MSCC	Multi-Spectral Spin Scan Cloud Camera
NASA	National Aeronautics and Space Administration

PACE	Phased Array Control Electronics
PCM	Pulse Coded Modulation
S/C	Spacecraft
SCOMB	Satellite Communication Oceanographic and Meteorological Buoy
SD	Standard Deviation
SSCC	Spin Scan Cloud Cover
T&C	Telemetry and Command
TWT	Traveling Wave Tube
VHF	Very High Frequency